NERC GEF Report (Loan 894, Leica 1200 GPS)

Mapping the Igwisi Hills kimberlite volcanoes, Tanzania: understanding how deep-sourced mantle magmas behave at the Earth`s surface

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Abstract

The Igwisi Hills volcanoes, Tanzania, are the youngest and best-preserved kimberlite volcanoes on Earth. Uniquely they preserve the surface deposits and constructs, which are absent at all other kimberlite volcanoes. They provide an unparalleled opportunity to investigate the eruptive dynamics of ultrabasic kimberlite magmas. The volcanoes are situated in a remote part of western Tanzania and detailed topographic maps and high resolution aerial photography do not exist. As part of a detailed field study of the volcanoes, a Leica 1200 differential GPS, loaned from GEF, was used to undertake a high resolution topographic survey of the Igwisi Hills volcanoes. RTK continuous GPS surveying of the volcanoes and their surrounds captured the morphology of the volcanoes and provided the base for the first detailed geological map of these unique edifices. The field study revealed important new insights into kimberlite volcanism, including the presence of viscous kimberlite lava flows (e.g., a lava coulee) and kimberlite cinder cones. The detailed GPS survey captured primary morphological features pertinent to understanding the nature of the eruptions and will help to constrain the volume of the volcanic constructs and the erupted products.

Background

Eruptions of ultrabasic magmas have not been witnessed by mankind, and the dynamics of their ascent, degassing or dispersal as pyroclasts or lavas at the surface are not well constrained (see Sparks et al., 2006). Kimberlites belong to a suite of ultramafic magmas that includes carbonatites and lamproites, and are characterised by inferred very low silica contents, high volatile contents and low magmatic viscosities (Mitchell, 1986). They derive from great depths (> 150 km) and entrain host rock from the mantle upwards during ascent. Despite their apparent abundance in the geological record (> 3000 known occurrences) kimberlite eruptions have been exceptionally sparse since the Middle Eocene (*ca*. 40 Ma; Kjarsgaard, 2007). Due to their great age most kimberlites have long had their surface deposits removed by erosion. All that remains for study are the deposits and intrusions preserved within their volcanic vents (kimberlite pipes). Volcaniclastic rocks preserved within these vents have proved problematic to interpret and a number of different, but not mutually exclusive, processes have been proposed and elaborated, including fluidisation (Dawson 1971; Field and Scott Smith, 1999; Sparks et al, 2006; Walters et al., 2006; Gernon et al., 2008a and b), phreatomagmatism (Lorenz, 1975; Lorenz and Kurslaukis, 2007; Kurszlaukis and Lorenz 2008; Ross and White, 2006), eruption column collapse (Porritt and Cas, 2008) and re-sedimentation (Moss et al., 2008).

It seems probable that many of these processes occurred to some degree in most kimberlite eruptions. Within-vent deposits are prone to intense alteration, which obscures primary depositional characteristics.

The youngest known kimberlite volcanoes, the Igwisi Hills volcanoes, Tanzania, (4°53'13.18"S 31°56'4.46"E) are thought to be Quaternary or younger and uniquely preserve the surface deposits and volcanic constructs (Dawson, 1994). Despite their well preserved nature, no systematic field studies have been undertaken: research has focussed entirely on their petrology and mineralogy (Sampson, 1953; Bassett, 1954; Fozzard, 1956; Reid et al., 1975; Dawson 1994). The volcanoes are located on the western side of the Tanzanian Craton and were emplaced through granitic gneiss basement of the Dodoman system that has been dated at 2500 +/- 100 Ma by Bell and Dodson (1981). The basement outcrops in small rounded kopjes near Igwisi village and occurs as xenoliths within the lavas and pyroclastic deposits.

We undertook fieldwork in tandem with RTK GPS surveying in order to construct a new geological map and describe and interpret the field relationships, macro-scale features, and petrography of the erupted products. Documentation of the surface products, combined with surveying allows greater insight into eruptive processes and tighter constraints on erupted volumes of volcanic products and the size of the volcanic edifices.

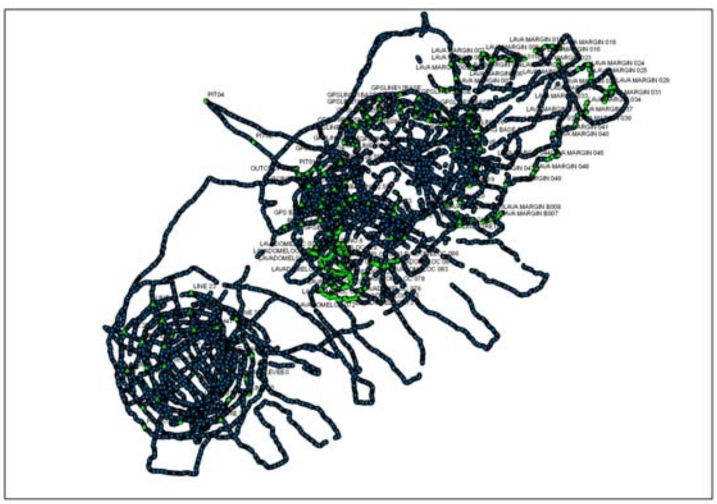

Figure 1. Continuous survey points along survey lines around the Igwisi volcanoes. Green triangles mark the position of static sample points.

Survey procedure

Reference base stations were set up on the summit of the Central volcano (1046 m altitude) to survey the NE and Central volcanoes and on the summit of SW volcano for its survey (1045 m altitude). RTK GPS surveys were operated continuously by one member of the team over a 5 day period to distances of < 1 km from the base station. The equipment was set up to automatically record a position every time the rover moved 50 cm horizontally or vertically. The survey patterns were designed to provide the optimal coverage of the volcanoes (concentrating on the volcanic edifices) in the limited time available and to take into account forest cover and the relief of the volcanoes. Issues with local bureaucracy resulted in delays and ate into the time available for surveying and fieldwork. Forest cover over the flat-lying parts of the volcanoes and on the surrounding plain blocked GPS satellite signals, resulting in occasional significant errors (taken as > 10 cm) in the measurements due to periodic loss of signal. The rugged topography of the volcanoes, including steep cliffs, scree slopes and fissured clint-and-gryke-type weathering of the carbonate-rich tuffs, meant that survey paths were often meandering. Geological boundaries, topographic features (ridges, breaks-in-slope, crater rims, edges of lava flows) were surveyed separately (as break-lines).

Data processing

GPS data were processed in Leica Geo office and imported into ARCGIS as ASCII files. Survey points with large errors (> 10 cm, due to loss of signal under tree cover) were removed prior to manipulation in ARCGIS. This did not significantly affect the outcome due to the large number and high quality of data points (n=50 000) collected during continuous surveying. A digital elevation model was created from the xyz points, the surface was kriged in ARCGIS and then contoured at 2 m intervals. The contour map is given in figure 2.

Point Id	Latitude	Longitude	Ell. height	Std. dev. H ellipse
FRI EVE 000903	4 53 33.432851 S	31 55 49.029296 E	1119.0512	0.0095
FRI EVE 000904	4 53 33.465563 S	31 55 49.043156 E	1118.7352	0.0037
FRI EVE 000905	4 53 33.499504 S	31 55 49.052748 E	1118.3794	0.0068
FRI EVE 000906	4 53 33.534614 S	31 55 49.064167 E	1118.057	0.0053
FRI EVE 000907	4 53 33.556337 S	31 55 49.090316 E	1117.9154	0.0082
FRI EVE 000908	4 53 33.569565 S	31 55 49.115613 E	1117.8363	0.0045
FRI EVE 000909	4 53 33.602056 S	31 55 49.133417 E	1117.5834	0.0058

Table 1. Sample data from the Igwisi survey.

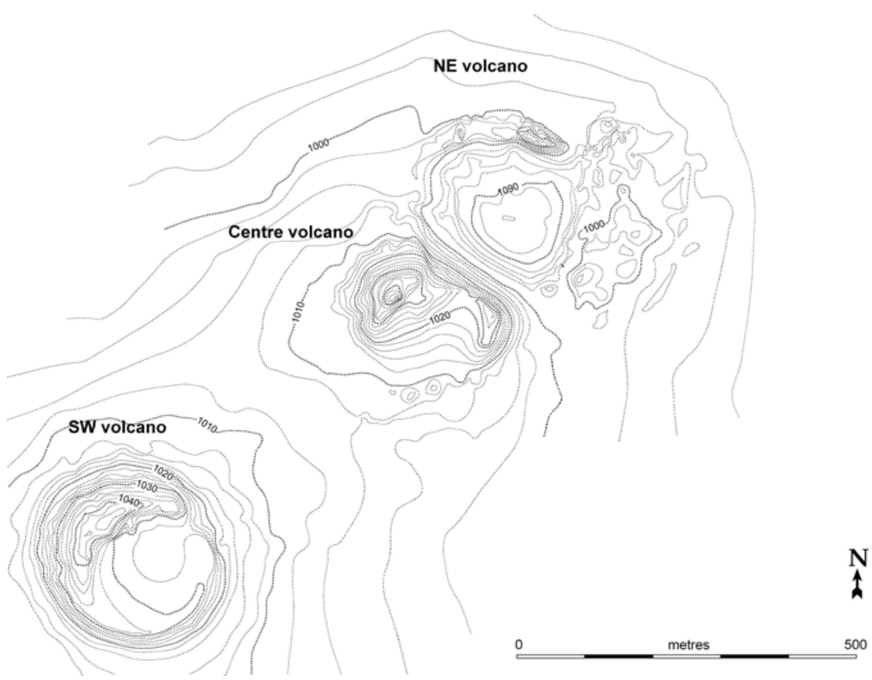

Figure 2. Contour lines (2 m intervals) extracted from a DEM created in ARCGIS.

Data Quality (including examples)

The Leica 1200 GPS system worked extremely well. Data during this survey were collected continuously, in order to maximise spatial coverage in the relatively short amount of time (time limitations became an issue due to bureaucratic delays). The density of survey lines was not sufficient to generate a DEM of high enough resolution at the scale needed, but nevertheless the data were of high quality (typical errors of <1 cm; Table 1) and were more than sufficient for the construction of the topographic and geological map (Figs 2 and 3), which was the prime objective of this project. The volcanic deposits are in places deeply (up to several metres) eroded and gullied; RTK GPS surveying captured this topographic detail, but it was of no scientific interest to us. The contour map provides an excellent representation of the topography (Fig. 2).

Interpretation

The GPS survey facilitated the construction of a topographic map (Fig. 2) which was then overlaid with the geological data, derived from surveying of geological boundaries and morphological features and from field investigations (e.g., dip and strike of beds). The result is the first detailed geological map of the surface deposits of a kimberlite volcano (Fig. 3). The volcanoes consist of three small volcanic centres (NE, Central and SW volcanoes) comprised of cones, craters and lavas. They are aligned NE-SW and sit upon a broad, low NE-SW-oriented ridge, 500 m wide probably comprised of pyroclastic material (poorly exposed) from early stages of the eruptions. This ridge is superimposed onto a gentle regional slope dipping NE. Relative ages of the volcanoes unknown, but products of the Central volcano partially bury those of the NE volcano. Pyroclastic deposits have been heavily weathered to a karst-like morphology comprising steep-sided fissures and upstanding blocks and most are cemented by calcite. The volcanoes have been partially buried by younger sedimentary deposits and soils, and are presently covered in grassland and low density Miombo forest. The pyroclastic cones rise > 30 m above the surrounding plain and we estimate that they have lost somewhere between 15 and s0 metres in height due to erosion.

The NE volcano comprises a flat-based sub-circular crater 250 m in diameter (Fig. 3). Crater walls on the northern side comprise a succession of bedded and stratified pyroclastic rocks; its eastern side is comprised of lava. The northern and western crater walls are presently 4-8 m higher than the eastern crater wall (Fig 3).The south-western crater wall has been buried by lava erupted from the Central volcano.

The central volcano is structurally simpler than the NE volcano (Fig. 3). The western side comprises an N-S oriented elongate mound of bedded tephra, in which beds dip towards the W, NW and SW. This tephra mound rises 36 m above the surrounding plain. The eastern margin of the mound is an N-S oriented, near-vertical crater wall and we infer that the crater was open to the east—pyroclastic deposits have not been recognised on the eastern, northern or southern sides of the volcano. The crater is inferred to be beneath a lava coulee that makes up the eastern half of the volcano.

The SW volcano is located 300 m SW of the central volcano (Fig. 3). It comprises a tephra cone that is sub-circular in plan view and which rises 32 m above the ground. The north and west walls of the crater rise 10 m higher than the south and east side and are breached on the northeast. It has a 180 m diameter flat-bottomed crater perched 12 m above the ground. The sides of the tephra cone are eroded. Bedding dips outwards at shallow angles and is uniformly steeper on the eastern side of the volcano than on the west (Fig. 3).

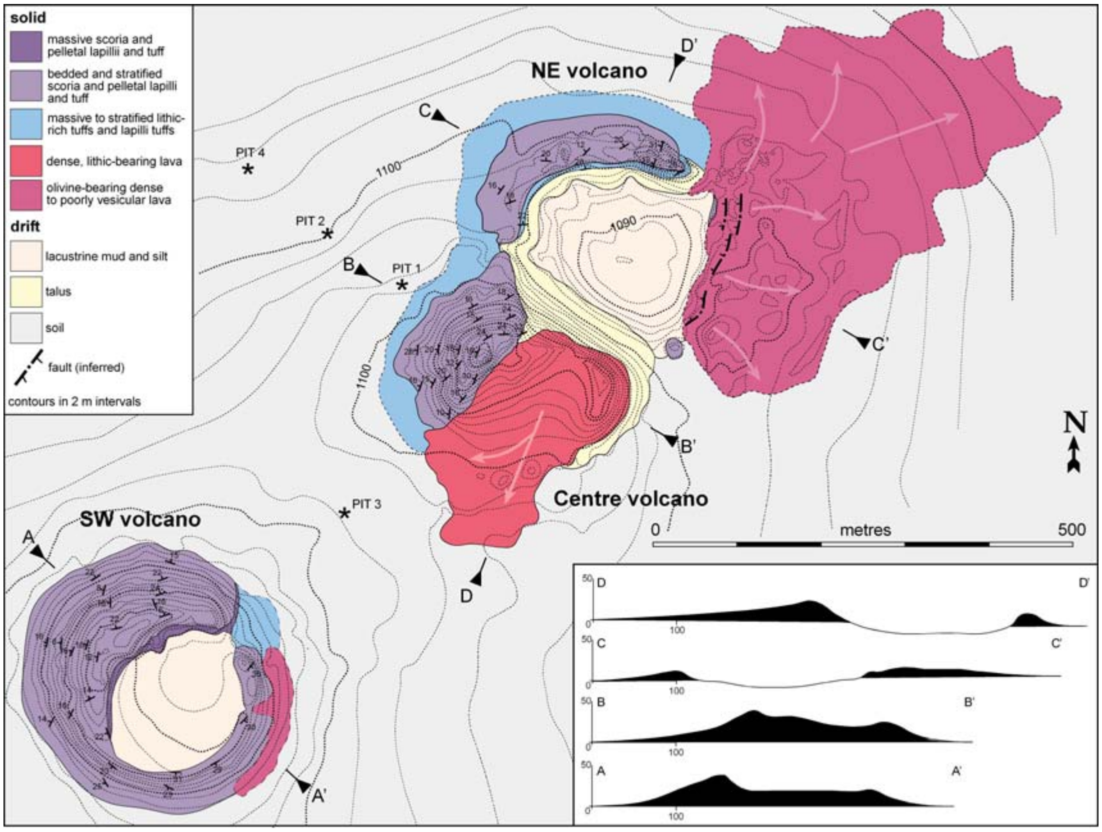

Figure 3. Detailed geological map of the Igwisi Hills volcanoes. Geological boundaries were surveyed using RTK continuous surveying. Cross-sections illustrate the present morphology of the volcanoes.

Preliminary findings

The geological and topographic survey has revealed features hitherto not reported from kimberlite volcanic systems. The Igwisi volcanoes are small in comparison with most known, (ancient) eroded kimberlite volcanoes, raising interesting questions about their preservation potential in the geological record. New discoveries include the recognition of extremely viscous kimberlite lavas (the lava coulee of the Central volcano) and kimberlite cinder cones, apparently without a substantial volcanic conduit (a 'kimberlite pipe'). The survey data will enable us to to construct 3D models of the volcanoes (using GEMCOM GEMS CAD software, for example) and to estimate the volumes of the volcanic deposits and the constructs (cinder cones), which has previously been impossible for kimberlite volcanoes.

Conclusions

The first detailed geological map of surface kimberlite volcanoes had been produced by a combination of GPS surveying and comprehensive volcanological field studies. This has captured the morphology of the volcanoes and their products and will allow the calculation of minimum erupted volumes for the volcanic products and the edifices. The study provides important new insights into this unique type of volcanic activity and has uncovered new features such as extremely viscous lava flows and kimberlite cinder cones. The combined survey and geological mapping has allowed these new features to be fully described. The study has provided a wealth of new information that will be vital in understanding the behaviour of these unusual magmas at the Earth's surface.

Outputs to date

Conference presentations

Brown RJ, Manya S, Field M, Fontana G, Sparks, RSJ, 2010. The Igwisi Hills volcanoes, Tanzania: superbly exposed examples of young kimberlite volcanism. Volcanic and Magmatic Studies Group, Glasgow, 4-6th January.

Manuscripts

Brown R.J., Manya S., Field M., Sparks R.S.J., Fontana G., in prep. The eruption of the Igwisi Hills Volcanoes, Tanzania: constraints on kimberlite volcanism from surface deposits. Bulletin of Volcanology.

Brown R.J., Manya S., Field M., Sparks R.S.J., Fontana G., in prep. The dynamics of explosive and effusive eruptions from kimberlite volcanoes: insights from the volcanic products of the Igwisi Hills volcanoes, Tanzania. Bulletin of Volcanology.

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